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RESEARCH MEMORANDUM

EXPERIMENTAL DATA CONCERNING THE EFFECT OF HIGH HEAT-INPUT
RATES ON THE PRESSURE DROP THROUGH RADIATOR TUBES

By

James J. Gallagher and Louis W. Habel

Langley Aeronautical Laboratory
Langley Field, Va.

**NATIONAL ADVISORY COMMITTEE
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SUMMARY

The pressure drops through electrically heated Inconel tubes with length-diameter ratios of 29.25, 58.50, 87.75, and 117.00 have been measured at entrance Mach numbers from approximately 0.12 to the value at which choking occurred. The heat-input rate was varied from zero to the highest values allowable without damaging the tubes. Experimental data and a number of computed variables are presented in tabular form.

INTRODUCTION

In reference 1 the effects of heating and compressibility on the pressure drop through tubes, as determined with the arrangement shown in figures 1 and 2, are presented for tubes of $\frac{L}{d} = 29.25, 58.50, 87.75,$ and 117.00. These data are presented at heat-input parameters, $\frac{H}{c_p g_m T_{r2}}$, from zero to 0.4, the latter figure representing a value above those encountered in typical present-day tubular-radiator installations. For the tube of $\frac{L}{d} = 29.25$, values of the heat-input parameter could not be obtained much greater than 0.3 because above this value the tubes became excessively hot. For the longer tubes, however, values larger than those presented in reference 1 were obtained, 1.3 being reached with the longest tube tested ($\frac{L}{d} = 117.00$). The low heat-input data were obtained to verify the theory presented in reference 2.

All of the data obtained in the investigation are presented in the present paper to make information available for special use.

SYMBOLS

A cross-sectional area of radiator tube, square feet
 a velocity of sound in air, feet per second

c_p	specific heat of air at constant pressure, Btu per pound per °F (0.24)
d	radiator-tube diameter, feet
g	acceleration of gravity, feet per second per second
H	heat added in radiator, Btu per second
L	length of radiator tube, feet
M	Mach number (v/a)
m	mass-flow rate, slugs per second (ρAv)
p	static pressure, pounds per square foot
Δp	total pressure at station 2 minus static pressure at station r_3 , pounds per square foot
R	Reynolds number $\left(\frac{\rho v d}{\mu} \text{ or } \frac{m d}{A_{r2} \mu} \right)$
T	free-stream air temperature, °F absolute
v	velocity in radiator tube, feet per second
ρ	density, slugs per cubic foot
μ	viscosity of air, pound-seconds per square foot
Subscripts:	
2	station ahead of radiator
r_2	station within radiator at tube entrances
r_3	station within radiator at tube exits

APPARATUS

A schematic diagram of the test setup is shown in figure 1. Air from the compressor and supply tank passed through a steam-heated radiator and two regulator valves before entering the surge tank ahead of the tube. The regulators allowed the surge-tank pressure to be maintained at any desired value. The preheat radiator was found to be unnecessary, as described in reference 1. The air flowed from the surge tank into the bell-mouth entrance to the tube, through the tube, exhausting into the atmosphere.

Tubes having length-diameter ratios of 29.25, 58.50, 87.75, and 117.00 were tested. The tubes were made from 0.25-inch Inconel tubing which was reamed and polished to a constant inside diameter of 0.205 inch. The tubes were heated by passing an electric current through them. (See figure 1.) Power was furnished by a bank of storage batteries and regulated by means of a slide-wire rheostat. The no-flow heat losses were determined in order to obtain the heat losses under test conditions. Each of the bell-mouth entrances to the tubes was calibrated so that the actual mass flow could be determined during the tests from measurements of pressure and temperature at station 2 and the pressure at station r_2 . The methods used in the heat-loss determinations and bell-mouth calibrations, as well as a further description of apparatus and the test method, are given in reference 1.

As discussed in reference 1, it was found necessary to fix the point of transition from laminar to turbulent flow at the tube entrance to obtain consistent data. Figure 2 shows the transition strip which was used. The strip consisted of a commercial iron cement (Smooth-on No. 1) a few thousandths of an inch thick and approximately $1/32$ of an inch wide.

RESULTS

In tables I to IV, data are presented for tubes of $\frac{L}{d} = 29.25$, 58.50, 87.75, and 117.00, respectively, with the transition fixed at the entrance. Each line of data in the tables represents a test point and each table is divided into groups of from six to nine test points. Each group of test points represents a series of test made at approximately constant pressure drops through the tubes. In each table the first five columns represent data which are measured values. These data are presented in units other than those in which the various parameters were measured. The heat input H is the actual heat input to the tube, the losses being subtracted from the measured values of the total heat input. The method used to determine the heat losses is explained in reference 1. The remaining columns are calculated data. The entrance Mach number M_{r_2} , the mass-flow rate m , and the Reynolds number R were computed from the measured entrance conditions. The exit Mach number M_{r_3} and temperature T_{r_3} were determined after the exit density ρ_{r_3} was computed as shown in reference 1. The pressure drops across the tubes were measured to the nearest millimeter of tetrabromoethane and are therefore believed accurate to approximately $1/2$ pound per square foot. The pressures p_2 and p_{r_3} are believed to be accurate to at least 1 pound per square foot. The temperature T_2 ahead of the tube is believed accurate to 1° Fahrenheit. To determine the tube exit conditions it was necessary to solve a simultaneous equation which involved a comparatively small difference of large numbers; hence M_{r_3} and T_{r_3} are probably accurate to only within approximately 3 or 4 percent for values of M_{r_3}

less than unity. When sonic velocity is attained at the tube exits, the accuracy with which the exit conditions may be calculated is considerably poorer. All remaining data are believed accurate to within approximately 1 percent.

It is noted that from zero to the extremely high heat-input ratio, no discontinuities or abrupt changes occur in any of the measured or computed quantities. Of particular interest is the exit Mach number M_{r_3} which is shown to remain approximately constant for any particular pressure drop through the tube regardless of the heat-input rate. In several instances the calculated exit Mach number is above unity. As the exit pressure p_{r_3} was assumed to be atmospheric, the true pressure at station r_3 is not known once sonic velocity is attained at the rear of the tube. Also, the basic assumptions made in deriving the one-dimensional theory which was used to compute the tube-exit conditions probably invalidate its use as the exit Mach number approaches unity.

Data obtained for the tube with the length-diameter ratio of 29.25 and a round smooth entrance are presented in table V. These data do not show quite the consistency of the data obtained with the point of transition fixed at the tube entrance because, as explained in reference 1, the addition of the heat apparently caused the point of transition to move forward in the tube even though the entrance Mach number and Reynolds number remained constant. Only limited data were obtained with the round smooth entrance as this condition in no way stimulates the tube entrances in actual tubular radiators which undoubtedly have turbulent flow throughout their entire length due to the sharp edges at the entrances.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

REFERENCES

1. Habel, Louis W., and Gallagher, James J.: Tests to Determine the Effect of Heat on the Pressure Drop through Radiator Tubes. NACA TN No. 1362, 1947.
2. Becker, John V., and Baals, Donald D.: Simple Curves for Determining the Effects of Compressibility on Pressure Drop through Radiators. NACA ACR No. L4I23, 1944.

TABLE I

TUBE L/d = 29.25

[Transition Fixed at Tube Entrance]

Δp	P_2	T_2	H	P_{r3}	M_{r2}	$m \times 10^5$	R	M_{r3}	T_{r3}	$\frac{H}{c_p g r_2}$
131.4	2254	542	0	2123	0.216	13.2	25,200	0.219	537	0
132.3	2255	542	.069	2123	.205	12.6	24,100	.217	574	.069
133.9	2257	542	.150	2123	.198	12.2	23,400	.218	617	.150
133.9	2257	542	.190	2123	.194	12.0	22,900	.218	640	.190
133.5	2257	542	.265	2123	.186	11.6	22,100	.216	679	.265
133.9	2257	543	.312	2123	.182	11.3	21,500	.215	705	.312
133.2	2256	543	.350	2123	.178	11.1	21,100	.214	726	.350
267.5	2391	543	0	2123	.323	19.1	36,800	.316	531	0
268.8	2392	544	.080	2123	.285	18.2	35,000	.314	575	.080
269.3	2392	544	.139	2123	.275	17.6	33,700	.311	607	.139
268.4	2391	544	.220	2123	.261	16.7	32,200	.307	650	.220
269.5	2393	544	.276	2123	.255	16.4	31,400	.307	680	.276
268.0	2391	547	.327	2123	.247	15.8	30,100	.303	712	.327
268.6	2392	547	.379	2123	.241	15.5	29,500	.303	739	.379
397.2	2530	547	0	2123	.357	23.4	45,000	.388	532	0
398.4	2531	547	.067	2123	.340	22.4	43,100	.384	567	.067
399.0	2532	548	.132	2123	.326	21.6	41,400	.382	602	.132
398.3	2531	548	.191	2123	.315	20.9	40,100	.378	632	.191
400.5	2534	548	.229	2123	.310	20.6	39,500	.379	653	.229
399.6	2533	548	.284	2123	.300	20.0	38,300	.376	682	.284
399.8	2533	548	.374	2123	.288	19.2	36,800	.374	730	.374
537.8	2661	549	0	2123	.403	27.2	52,600	.450	528	0
539.5	2663	549	.070	2123	.383	26.1	50,300	.447	565	.070
540.2	2663	549	.130	2123	.369	25.3	48,700	.444	596	.130
540.7	2664	549	.187	2123	.355	24.5	47,100	.442	626	.187
541.4	2664	549	.266	2123	.340	23.6	45,300	.439	667	.266
542.1	2665	549	.319	2123	.331	23.1	44,300	.438	694	.319
541.4	2664	549	.357	2123	.324	22.6	43,400	.436	715	.357
1085	3208	551	0	2123	.505	39.2	76,700	.637	510	0
1085	3208	551	.098	2123	.481	37.7	73,300	.631	542	.098
1085	3208	551	.189	2123	.460	37.4	70,600	.627	574	.189
1086	3209	551	.300	2123	.438	35.0	67,700	.624	614	.300
1087	3210	551	.353	2123	.428	34.4	66,700	.624	634	.353
1087	3210	551	.394	2123	.419	33.7	65,200	.620	651	.394
1088	3211	551	.433	2123	.413	33.4	64,500	.621	668	.433
1631	3754	552	0	2123	.545	48.6	95,500	.777	494	0
1636	3759	552	.101	2123	.527	47.4	93,000	.777	518	.101
1642	3765	552	.247	2123	.500	45.7	89,100	.776	556	.247
1630	3753	552	.343	2123	.483	43.9	85,500	.765	584	.343
1640	3763	552	.430	2123	.469	43.4	84,200	.770	608	.430
1637	3760	552	.517	2123	.456	42.2	81,900	.766	635	.517
2554	4677	552	0	2123	.567	62.6	123,700	.973	466	0
2545	4668	552	.144	2123	.545	60.4	118,800	.965	492	.144
2547	4670	552	.268	2123	.528	59.0	115,700	.964	515	.268
2546	4669	552	.381	2123	.512	57.5	112,600	.961	538	.381
2544	4667	552	.488	2123	.497	56.1	109,500	.957	561	.488
2549	4672	552	.633	2123	.479	54.7	106,400	.958	592	.633

TABLE II

TUBE L/d = 58.50

[Transition Fixed at Tube Entrance]

Δp	P_2	T_2	H	P_{r3}	M_{r2}	$m \times 10^5$	R	M_{r3}	T_{r3}	$\frac{H}{c_p g m r_2}$
134.8	2248	537	0	2113	0.182	11.3	21,800	0.188	533	0
134.6	2248	537	.028	2113	.175	10.8	20,800	.185	567	.060
134.9	2248	537	.056	2113	.168	10.4	20,100	.185	603	.129
135.3	2248	537	.109	2113	.156	9.70	18,700	.183	678	.271
135.7	2249	537	.174	2113	.143	8.93	17,200	.181	786	.469
135.7	2249	537	.222	2113	.135	8.51	16,400	.181	870	.627
135.8	2249	537	.234	2113	.135	8.42	16,100	.182	894	.665
307.5	2420	543	0	2112	0.268	17.4	33,600	0.292	534	0
308.0	2420	543	.046	2112	.258	16.8	32,300	.290	568	.065
307.8	2420	543	.090	2112	.249	16.2	31,100	.288	604	.133
308.0	2420	543	.137	2112	.239	15.6	30,000	.287	646	.211
308.2	2420	543	.202	2112	.227	14.8	28,400	.285	708	.329
309.3	2421	543	.256	2112	.219	14.3	27,400	.286	762	.429
309.7	2422	543	.319	2112	.207	13.6	26,100	.285	832	.561
310.3	2422	543	.395	2112	.194	12.9	24,600	.284	926	.735
401.8	2514	545	0	2112	.302	20.0	38,600	0.335	535	0
403.2	2515	545	.064	2112	.288	19.2	36,900	.334	575	.080
403.4	2515	545	.120	2112	.276	18.5	35,500	.333	615	.156
403.6	2516	545	.186	2112	.262	17.7	33,800	.330	667	.253
404.6	2517	545	.285	2112	.245	16.6	31,700	.329	752	.413
404.8	2517	545	.365	2112	.232	15.7	30,000	.327	828	.557
405.4	2517	545	.449	2112	.217	14.7	28,200	.324	920	.728
814.5	2927	545	0	2112	.393	29.4	57,100	.486	521	0
815.0	2927	545	.084	2112	.375	28.3	54,700	.484	557	.073
815.8	2928	545	.145	2112	.364	27.6	53,400	.484	586	.128
818.4	2930	545	.267	2112	.342	26.2	50,600	.482	647	.247
817.8	2930	545	.330	2112	.330	25.3	48,900	.479	682	.315
818.9	2931	545	.441	2112	.312	24.2	46,500	.479	747	.441
819.8	2932	545	.669	2112	.279	21.8	41,800	.474	903	.740
819.7	2932	545	.603	2112	.291	22.6	43,400	.478	851	.642
1362	3481	543	0	2119	.451	39.1	76,800	.633	503	0
1364	3483	543	.119	2119	.431	37.7	73,800	.633	541	.078
1364	3483	543	.219	2119	.414	36.5	71,400	.632	574	.147
1367	3486	543	.299	2119	.399	35.5	69,300	.630	604	.206
1369	3488	543	.428	2119	.380	34.1	66,300	.630	654	.306
1367	3486	543	.539	2119	.363	32.9	63,800	.627	700	.400
1369	3488	543	.693	2119	.344	31.4	60,800	.627	768	.538
1370	3489	543	.765	2119	.334	30.7	59,400	.627	803	.606
2176	4295	542	0	2119	0.489	51.5	101,800	0.812	479	0
2177	4296	542	.112	2119	.471	50.0	98,600	.811	505	.056
2207	4326	542	.229	2119	.454	48.7	95,700	.812	533	.117
2178	4297	542	.390	2119	.432	46.7	91,500	.808	576	.206
2179	4298	542	.514	2119	.416	45.3	88,700	.808	609	.279
2182	4301	542	.664	2119	.399	43.9	85,700	.809	652	.371
2181	4300	542	.827	2119	.376	41.8	81,500	.802	706	.485
2184	4303	542	.965	2119	.363	40.6	79,200	.803	751	.582
2740	4874	539	0	2134	.498	59.5	118,500	.916	461	0
2739	4873	539	.094	2134	.482	57.9	114,900	.910	481	.041
2740	4874	539	.239	2134	.466	56.5	111,700	.914	510	.106
2739	4873	539	.358	2134	.451	55.0	108,500	.911	535	.162
2740	4874	539	.500	2134	.435	53.4	105,300	.910	566	.233
2741	4875	539	.658	2134	.416	51.6	101,400	.908	605	.316
2742	4876	539	.804	2134	.402	50.2	98,500	.910	640	.396
2744	4878	539	.912	2134	.390	49.1	96,200	.909	669	.458
2744	4878	539	1.13	2134	.372	47.2	92,200	.911	728	.587

TABLE III

TUBE L/d = 87.75

[Transition Fixed at Tube Entrance]

Δp	P_2	T_2	H	Pr_3	Mr_2	$m \times 10^5$	R	Mr_3	Tr_3	$\frac{H}{\rho_p g m r_2}$
133.9	2247	548	0	2113	0.154	9.67	18,340	0.163	545	0
134.7	2248	549	.053	2113	.143	9.01	17,050	.163	623	.140
135.1	2248	549	.105	2113	.134	8.49	16,060	.163	706	.292
135.9	2249	545	.142	2113	.124	8.07	15,350	.162	768	.417
137.4	2250	546	.183	2113	.119	7.79	14,810	.164	845	.556
137.8	2251	541	.224	2113	.111	7.34	14,030	.162	933	.731
137.8	2251	543	.270	2113	.107	7.05	13,410	.164	1032	.910
265.7	2363	544	0	2097	.218	13.9	26,600	.235	538	0
267.6	2365	544	.090	2097	.200	12.8	24,500	.235	628	.168
268.8	2366	544	.180	2097	.184	11.9	22,800	.236	730	.360
269.9	2367	544	.242	2097	.173	11.3	21,500	.234	813	.513
271.0	2368	544	.313	2097	.161	10.6	20,100	.233	917	.705
272.8	2370	538	.379	2097	.152	10.2	19,600	.236	1008	.897
273.1	2370	538	.425	2097	.147	9.82	18,900	.236	1087	1.04
273.3	2370	538	.462	2097	.146	9.75	18,700	.239	1139	1.14
399.5	2497	538	0	2097	.260	17.5	33,900	.293	529	0
401.0	2498	538	.112	2097	.239	16.1	31,200	.292	617	.168
401.1	2498	539	.197	2097	.224	15.2	29,300	.292	695	.313
402.5	2500	539	.272	2097	.207	14.1	27,200	.286	776	.466
403.4	2500	540	.393	2097	.193	13.2	25,300	.290	910	.716
405.0	2502	540	.467	2097	.183	12.6	24,200	.290	1004	.894
405.7	2503	540	.548	2097	.174	12.0	23,100	.292	1111	1.10
405.9	2503	540	.586	2097	.170	11.8	22,600	.293	1164	1.20
540.7	2652	532	0	2111	.293	20.9	40,500	.346	525	0
542.7	2654	532	.116	2111	.272	19.5	37,900	.346	600	.144
544.3	2655	533	.246	2111	.251	18.0	34,800	.344	699	.331
545.1	2656	534	.359	2111	.234	16.8	32,400	.344	796	.517
546.4	2657	534	.459	2111	.219	15.8	30,400	.342	895	.701
547.3	2658	534	.543	2111	.209	15.1	29,100	.341	982	.866
548.2	2659	534	.625	2111	.201	14.7	28,100	.346	1067	1.03
548.9	2660	535	.720	2111	.192	14.0	26,800	.347	1180	1.24
674.5	2790	537	0	2115	.319	23.7	46,300	.391	521	0
677.4	2792	537	.142	2115	.293	22.0	42,700	.390	603	.158
680.1	2795	537	.285	2115	.272	20.5	39,800	.391	695	.338
681.0	2796	537	.406	2115	.253	19.1	37,100	.388	788	.517
682.2	2797	538	.538	2115	.238	18.0	34,800	.390	897	.723
683.1	2798	538	.632	2115	.226	17.2	33,200	.390	985	.890
683.7	2799	538	.706	2115	.219	16.7	31,200	.391	1055	1.03
684.8	2800	538	.802	2115	.210	16.0	30,900	.393	1150	1.21
805.6	2921	538	0	2115	.341	26.2	51,100	.431	519	0
807.6	2922	538	.128	2115	.318	24.7	48,000	.431	583	.127
811.3	2926	538	.314	2115	.290	22.7	44,000	.431	692	.338
812.6	2928	539	.442	2115	.270	21.3	41,300	.430	778	.504
814.1	2929	539	.542	2115	.258	20.4	39,300	.430	852	.645
815.6	2931	539	.683	2115	.241	19.1	36,900	.430	965	.865
816.5	2932	539	.843	2115	.229	18.2	35,000	.435	1099	1.12
817.2	2932	539	.907	2115	.223	17.7	34,100	.436	1159	1.24

TABLE III - Concluded

TUBE L/a = 87.75

Δp	P_2	T_2	H	P_{r3}	M_{r2}	$m \times 10^5$	R	M_{r3}	T_{r3}	$\frac{H}{c_p g \Delta T_{r2}}$
1078	3193	539	0	2115	0.371	30.7	60,100	0.503	512	0
1081	3196	539	.229	2115	.332	28.0	54,500	.501	614	.200
1083	3198	539	.383	2115	.311	26.5	51,500	.504	691	.352
1086	3201	539	.520	2115	.293	25.1	48,700	.503	768	.504
1088	3203	539	.659	2115	.277	23.8	46,100	.505	858	.672
1089	3204	539	.828	2115	.261	22.5	43,500	.506	966	.893
1091	3206	539	.965	2115	.247	21.4	41,400	.506	1068	1.09
1091	3206	539	1.019	2115	.243	21.1	40,700	.507	1108	1.17
1613	3743	538	0	2130	.408	39.1	76,900	.627	499	0
1615	3745	540	.242	2130	.371	36.1	70,500	.624	581	.165
1618	3748	540	.433	2130	.347	34.1	66,400	.626	653	.311
1619	3749	540	.609	2130	.326	32.2	62,600	.626	731	.461
1623	3753	540	.802	2130	.306	30.6	59,400	.629	819	.638
1625	3755	541	.947	2130	.293	29.4	56,800	.631	892	.781
1626	3756	541	1.08	2130	.282	28.5	55,000	.632	957	.922
1628	3758	541	1.19	2130	.272	27.5	53,200	.631	1020	1.05
2160	4290	541	0	2130	.427	46.3	90,800	.738	489	0
2164	4294	541	.250	2130	.393	43.5	84,900	.736	556	.142
2165	4295	541	.498	2130	.365	40.8	79,300	.735	631	.299
2168	4298	541	.733	2130	.342	38.5	74,800	.737	710	.464
2170	4300	541	.896	2130	.326	37.0	71,600	.738	771	.590
2172	4302	542	1.06	2130	.311	35.6	68,700	.739	837	.724
2173	4303	542	1.22	2130	.303	34.7	67,000	.745	896	.851
2175	4305	542	1.36	2130	.291	33.4	64,500	.744	963	.988
2177	4307	542	1.50	2130	.283	32.7	63,100	.749	1020	1.11
2704	4827	545	0	2123	.438	53.0	103,400	.835	479	0
2710	4833	545	.310	2123	.401	49.5	96,200	.836	549	.153
2712	4835	545	.588	2123	.371	46.3	89,700	.843	638	.308
2714	4837	545	.782	2123	.355	44.7	86,300	.838	678	.424
2715	4838	545	1.04	2123	.334	42.3	81,500	.839	759	.596
2719	4842	545	1.23	2123	.320	40.7	78,400	.840	822	.730
2721	4844	545	1.42	2123	.304	39.1	75,100	.839	890	.874
2722	4845	545	1.60	2123	.298	38.2	73,300	.848	953	1.01
3390	5513	548	0	2123	0.445	61.2	119,100	.949	464	0
3395	5518	548	.356	2123	.409	57.2	110,900	.952	532	.151
3396	5519	548	.617	2123	.385	54.4	105,100	.951	588	.275
3398	5521	548	.920	2123	.360	51.5	99,100	.951	660	.432
3401	5524	548	1.19	2123	.340	49.0	94,100	.953	730	.586
3405	5528	548	1.40	2123	.326	47.4	90,700	.956	786	.709
3406	5529	548	1.58	2123	.315	45.9	87,900	.959	840	.828
3410	5533	548	1.91	2123	.300	43.9	84,200	.968	935	1.04
4076	6199	542	0	2123	.451	69.8	137,300	1.06	443	0
4080	6203	543	.327	2123	.419	66.1	128,900	1.06	496	.122
4085	6208	543	.753	2123	.383	61.7	119,800	1.06	572	.298
4086	6209	543	1.04	2123	.364	58.7	114,000	1.06	630	.432
4090	6213	543	1.34	2123	.339	55.9	108,300	1.06	696	.582
4092	6215	543	1.58	2123	.331	54.1	104,700	1.07	750	.711
4095	6218	543	1.79	2123	.320	52.5	101,500	1.07	801	.825
4097	6220	543	2.07	2123	.305	50.4	97,400	1.07	874	1.00

TABLE IV

TUBE $L/d = 117.00$

[Transition Fixed at Tube Entrance]

Δp	p_2	T_2	H	P_{r3}	M_{r2}	$m \times 10^5$	R	M_{r3}	T_{r3}	$\frac{H}{c_p g m r_2}$
135.0	2243	540	0	2108	0.132	8.82	16,900	0.150	549	0
136.0	2244	540	.101	2108	.117	7.64	14,600	.160	627	.316
136.2	2244	540	.154	2108	.107	7.05	13,500	.148	837	.524
136.5	2245	540	.197	2108	.099	6.67	12,700	.148	937	.705
136.9	2245	540	.239	2108	.092	6.25	11,900	.147	1049	.916
137.1	2245	540	.262	2108	.090	6.18	11,800	.149	1102	1.01
267.4	2375	542	0	2108	.194	12.6	24,200	.215	543	0
269.7	2378	543	.109	2108	.175	11.5	21,900	.217	667	.226
271.6	2380	543	.228	2108	.154	10.3	19,700	.217	830	.528
272.3	2380	543	.318	2108	.139	9.44	18,000	.217	981	.805
272.5	2381	543	.371	2108	.131	8.96	17,100	.216	1082	.987
273.1	2381	543	.425	2108	.126	8.60	16,400	.217	1186	1.18
272.7	2381	544	.445	2108	.123	8.44	16,100	.217	1230	1.25
399.4	2507	544	0	2108	.233	15.8	30,300	.268	547	0
400.4	2508	544	.114	2108	.213	14.4	27,700	.267	651	.189
402.2	2510	544	.222	2108	.196	13.4	25,600	.268	764	.397
403.7	2512	544	.295	2108	.183	12.6	24,200	.268	851	.558
404.7	2513	544	.375	2108	.172	12.0	22,800	.268	957	.749
405.6	2514	544	.472	2108	.158	11.1	21,100	.267	1101	1.01
406.4	2514	545	.549	2108	.147	10.3	19,700	.264	1241	1.26
539.4	2647	545	0	2108	.265	18.7	35,900	.317	545	0
542.0	2650	545	.239	2108	.226	16.1	30,800	.318	738	.354
543.4	2651	545	.337	2108	.211	15.2	29,000	.317	833	.532
544.6	2653	546	.448	2108	.197	14.2	27,100	.318	955	.752
545.7	2654	546	.551	2108	.183	13.3	25,400	.318	1081	.985
546.4	2654	546	.605	2108	.178	13.0	24,600	.319	1152	1.11
547.1	2655	546	.663	2108	.169	12.4	23,500	.316	1241	1.28
679.1	2809	536	0	2130	.290	21.9	42,600	.359	522	0
683.2	2813	535	.256	2130	.250	19.1	37,100	.360	690	.328
684.5	2815	536	.410	2130	.228	17.5	33,800	.359	820	.572
685.7	2816	537	.519	2130	.216	16.6	32,000	.360	918	.759
686.6	2817	537	.599	2130	.205	15.8	30,600	.359	1002	.917
687.7	2818	537	.695	2130	.195	15.0	29,000	.359	1108	1.12
688.6	2819	537	.797	2130	.184	14.3	27,600	.359	1227	1.35
809.4	2940	537	0	2130	.306	24.0	46,800	.393	521	0
813.9	2944	537	.247	2130	.268	21.3	41,300	.395	667	.283
815.6	2946	537	.421	2130	.245	19.6	37,900	.395	791	.523
815.8	2946	537	.497	2130	.236	18.8	36,400	.394	853	.641
817.5	2948	537	.613	2130	.223	17.9	34,600	.396	951	.831
819.0	2949	537	.724	2130	.211	16.9	32,700	.395	1057	1.04
819.5	2950	537	.857	2130	.198	15.9	30,700	.395	1199	1.31

TABLE IV - Concluded

TUBE L/d = 117.00

Δp	P_2	T_2	H	P_{r3}	M_{r2}	$m \times 10^5$	R	M_{r3}	T_{r3}	$\frac{H}{c_p g \sqrt{T_{r2}}}$
1081	3211	537	0	2130	0.335	28.5	55,500	0.463	515	0
1084	3214	537	.228	2130	.300	25.8	50,300	.464	625	.215
1088	3218	538	.387	2130	.280	24.3	47,100	.465	714	.389
1089	3219	538	.559	2130	.262	22.6	43,800	.465	823	.602
1091	3221	538	.727	2130	.244	21.3	41,100	.468	940	.830
1093	3223	539	.869	2130	.229	20.0	38,600	.467	1056	1.05
1094	3224	540	.994	2130	.217	19.0	36,500	.465	1168	1.26
1616	3746	540	0	2130	.370	36.0	70,300	.582	506	0
1619	3749	540	.326	2130	.325	32.2	62,500	.579	629	.247
1623	3753	541	.473	2130	.312	31.2	60,300	.588	691	.369
1625	3755	541	.672	2130	.292	29.2	56,500	.588	785	.558
1627	3757	541	.866	2130	.273	27.6	53,300	.589	886	.760
1629	3759	541	1.07	2130	.255	25.9	49,900	.589	1004	.993
1631	3761	541	1.20	2130	.240	24.3	46,900	.581	1105	1.19
2163	4293	541	0	2130	.389	43.2	84,200	.689	494.2	0
2167	4297	541	.377	2130	.346	39.0	75,900	.691	608.0	.236
2169	4299	542	.539	2130	.331	37.4	72,700	.693	664.0	.350
2173	4303	542	.761	2130	.309	35.4	68,400	.696	748.1	.521
2174	4304	542	.973	2130	.291	33.4	64,600	.695	837.5	.704
2178	4308	542	1.23	2130	.272	31.4	60,500	.698	956.3	.946
2180	4310	542	1.44	2130	.254	29.4	56,700	.692	1073.9	1.18
2712	4842	537	0	2130	.401	50.0	98,400	.785	478.0	0
2715	4845	537	.295	2130	.369	46.7	91,600	.787	551.0	.156
2717	4847	537	.542	2130	.347	44.3	86,600	.790	618.0	.301
2720	4850	537	.844	2130	.321	41.3	80,600	.791	712.3	.501
2725	4855	538	1.09	2130	.301	39.2	76,200	.794	799.0	.682
2729	4859	539	1.40	2130	.274	36.7	71,000	.796	914.2	.930
2732	4862	540	1.71	2130	.261	34.1	65,900	.797	1055.7	1.21
3397	5515	545	0	2118	.409	57.4	111,600	0.899	470.0	0
3399	5517	545	.297	2118	.381	54.1	105,000	.900	530.5	.134
3400	5518	545	.607	2118	.345	50.9	98,400	.906	606.4	.289
3404	5522	545	.970	2118	.327	47.5	91,500	.905	695.8	.494
3410	5528	545	1.19	2118	.312	45.7	88,100	.909	757.8	.629
3412	5530	545	1.51	2118	.291	42.8	82,300	.906	859.2	.846
3417	5535	545	1.90	2118	.269	39.9	76,600	.891	958.0	1.14
4078	6196	545	0	2118	.414	65.1	126,700	1.00	454.1	0
4083	6201	545	.310	2118	.387	61.7	119,800	1.00	507.6	.122
4087	6205	545	.563	2118	.368	59.2	114,600	1.01	555.6	.231
4087	6205	545	.844	2118	.349	56.4	108,900	1.01	613.7	.363
4093	6211	545	1.21	2118	.323	52.9	101,800	1.01	698.1	.551
4097	6215	545	1.60	2118	.300	49.6	95,500	1.01	800.1	.780
4098	6216	545	1.72	2118	.296	48.7	93,800	1.01	830.2	.849
4104	6222	545	2.08	2118	.276	46.0	88,400	1.02	937.6	1.09

TABLE V

TUBE L/d = 29.25

[Normal Transition]

Δp	P_2	T_2	H	Pr_3	Mr_2	$m \times 10^5$	R	Mr_3	T_{r3}	$\frac{H}{c_p g m T_{r2}}$
49.17	2195	539	0	2146	0.144	8.83	16,900	0.146	537	0
49.26	2195	540	.020	2146	.134	8.29	15,900	.141	567	.058
49.17	2195	540	.036	2146	.126	7.81	15,000	.136	596	.110
49.57	2196	540	.055	2146	.119	7.44	14,300	.133	631	.176
49.79	2196	540	.070	2146	.111	7.02	13,400	.129	667	.239
136.2	2282	540	0	2146	.244	15.0	28,800	.246	534	0
135.2	2281	540	.023	2146	.235	14.5	27,900	.242	553	.038
135.3	2281	540	.050	2146	.225	13.9	26,800	.238	580	.087
136.2	2282	540	.074	2146	.215	13.4	25,800	.235	605	.133
136.7	2283	540	.100	2146	.206	12.9	24,700	.231	634	.186
136.1	2282	540	.124	2146	.196	12.2	23,400	.224	665	.245
553.7	2687	536	0	2133	.458	30.8	61,100	.498	510	0
553.9	2687	536	.026	2133	.448	30.3	60,000	.495	521	.021
551.7	2685	536	.069	2133	.417	28.6	56,400	.477	542	.060
550.8	2684	536	.122	2133	.392	27.1	53,400	.464	570	.112
552.0	2685	536	.157	2133	.378	26.4	51,800	.459	588	.148
552.6	2686	536	.234	2133	.362	25.5	50,000	.446	629	.227
1126	3259	536	0	2133	.560	43.4	87,700	.690	490	0
1117	3250	536	.061	2133	.533	41.8	83,900	.676	509	.037
1110	3243	536	.089	2133	.517	40.7	81,500	.664	519	.056
1104	3237	536	.156	2133	.490	39.0	77,900	.651	541	.101
1102	3235	537	.308	2133	.451	36.5	72,300	.639	597	.211
1098	3231	537	.437	2133	.426	34.9	68,900	.635	647	.312
1100	3233	537	.379	2133	.436	35.6	70,400	.637	624	.265
1691	3824	538	0	2133	.590	52.9	107,000	.855	475	0
1677	3810	538	.091	2133	.565	51.1	103,000	.817	496	.045
1647	3780	538	.225	2133	.521	47.6	95,200	.789	533	.120
1644	3777	538	.364	2133	.492	45.6	90,700	.781	571	.201
1637	3770	538	.433	2133	.480	44.5	88,500	.777	592	.244
1638	3771	538	.535	2133	.462	43.3	85,800	.775	623	.309
2650	4783	538	0	2133	.602	67.0	135,700	1.02	453	0
2610	4743	538	.105	2133	.579	64.7	130,700	1.00	467	.040
2584	4717	538	.278	2133	.542	61.2	122,700	.980	500	.116
2574	4707	538	.390	2133	.523	59.4	118,800	.975	524	.166
2568	4701	537	.520	2133	.502	57.7	115,000	.970	551	.227
2567	4700	537	.588	2133	.492	56.8	113,000	.968	566	.260

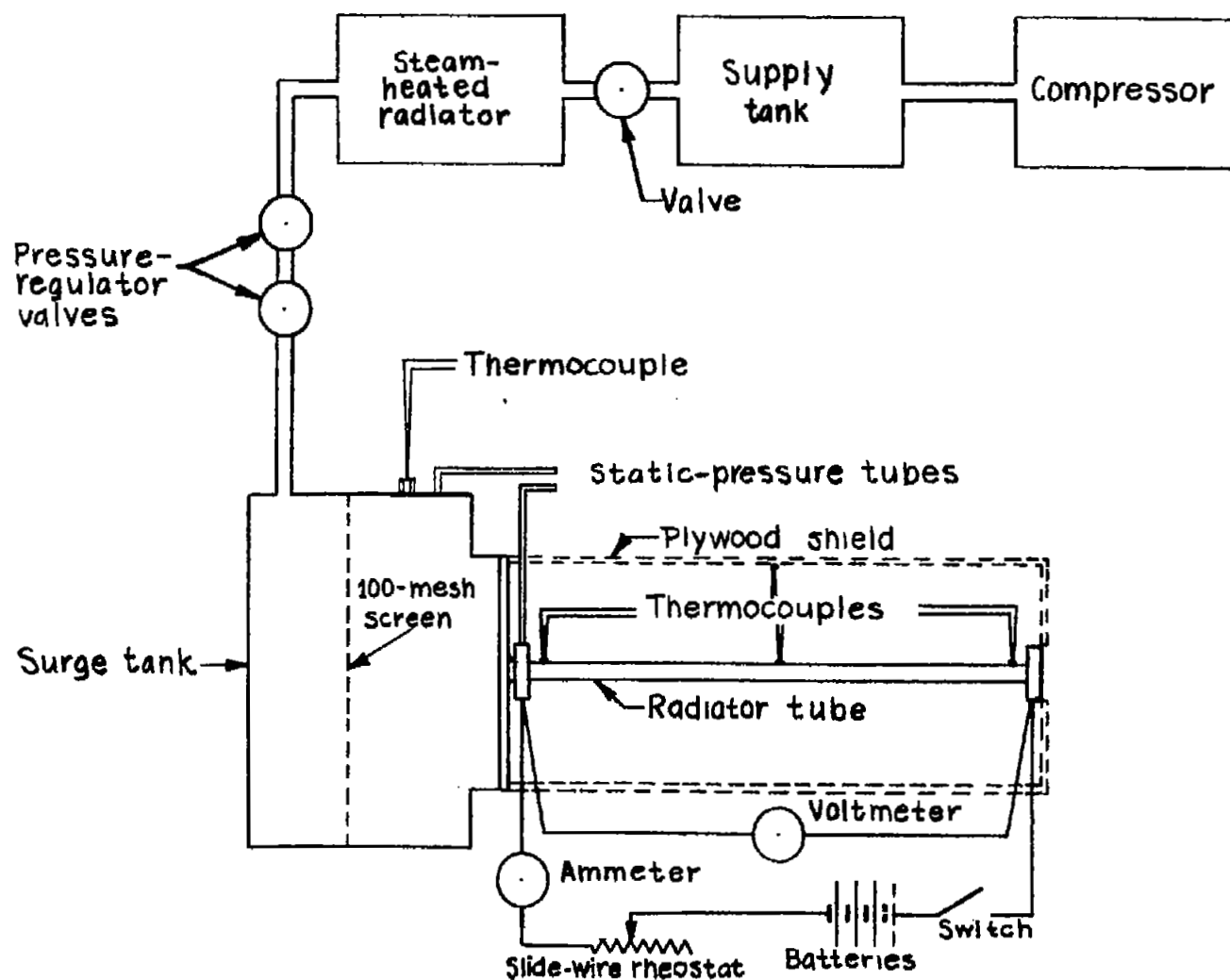


Figure 1.- Schematic diagram of test setup.

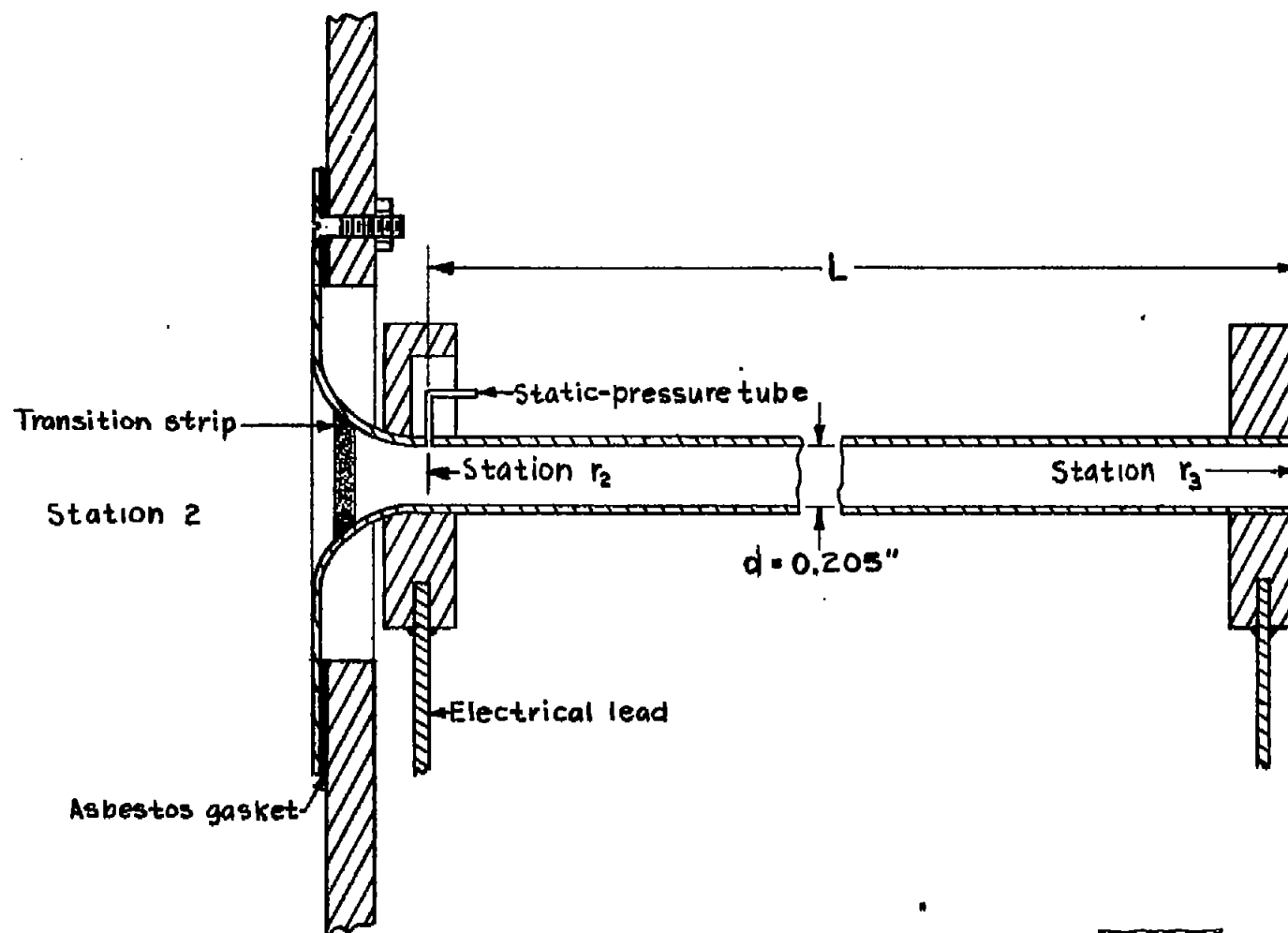


Figure 2.- Section through radiator tube.

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